This reference design supports design of 1200 V Motion SPM® 3 module. It should be used in conjunction with the 1200 V Motion SPM 3 series datasheets as well as Fairchild’s application notes AN-9095, AN-9086. For more information, please visit Fairchild’s website at https://www.fairchildsemi.com.

<table>
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<tr>
<th>Application</th>
<th>Fairchild Device</th>
<th>IGBT Rating</th>
<th>Motor Rating (1)</th>
<th>Isolation Voltage</th>
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<tr>
<td>System Air Conditioner, Industrial Inverters</td>
<td>FSBB10CH120D</td>
<td>10 A / 1200 V</td>
<td>3.2 kW / 440 VAC</td>
<td>$V_{ISO} = 2500 V_{RMS}$ (Sine 60 Hz, 1 min. Between all shorted pins and heat sink)</td>
</tr>
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Notes:
1. This motor rating is a typical value and may change depending on the operating conditions.

Key Features
- 1200 V 10 A 3-Phase IGBT Inverter Including Control ICs for Gate Driving and Protections
- Very Low Thermal Resistance by Adopting DBC Substrate
- Divided Negative DC-Link Terminals for Inverter Three-Leg Current Sensing
- Single-Grounded Power Supply due to Built-in HVICs and Bootstrap Operations
- Isolation Rating of 2500 $V_{RMS}$ / min

MMSZ5252B
- General Purpose, Medium Current Surface Mount Zener in the SOD-123 Package
- Compact Surface Mounting with Same Footprint as Mini-Melf
- 500 mW Rating on FR-4 or FR-5 Board
- Standard Zener Voltage(VZ) Tolerance is ±5%
- Typical Zener Voltage(VZ) is 24 V
1. Block Diagram

Figure 1. Block Diagram of Outdoor Fan Motor for Air-Conditioner (Direct Coupling)
2. Schematic

Figure 2. Schematic of Reference Design for 3-Phase Inverter Part (Direct Coupling)
3. Key Parameter Design

3.1. Selection of Bootstrap Capacitance ($C_{BS}$)

The bootstrap capacitor value can be calculated by Equation (1):

$$C_{BS} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}}$$

where:

- $\Delta t$ = maximum ON-pulse width of high-side IGBT;
- $\Delta V_{BS}$ = the allowable discharge voltage of the $C_{BS}$ (voltage ripple);
- $I_{Leak}$ = maximum discharge current of the CBS consisting of:
  - Gate charge for turning the high-side IGBT on
  - Quiescent current to the high-side circuit in the IC
  - Level-shift charge required by level-shifters in IC
  - Leakage current in the bootstrap diode
  - $C_{BS}$ capacitor leakage current (can be ignored for non-electrolytic capacitors)
  - Bootstrap diode reverse recovery charge

Practically, 4.5 mA of $I_{Leak}$ is recommended for FSBB10CH120D ($I_{PBS}$, operating $V_{BS}$ supply current at 20 kHz, is max. 4.5 mA in the datasheet).

✔ Calculation examples of $C_{BS}$:

- $I_{Leak} = 4.5$ mA
- $\Delta V_{BS} = 0.1$ V (recommended value)
- $\Delta t = 0.2$ ms (depends on user system)

$$C_{BS\_min} = \frac{I_{Leak} \times \Delta t}{\Delta V_{BS}} = \frac{4.5\text{mA} \times 0.2\text{ms}}{0.1\text{V}} = 9.0 \times 10^{-5}$$

More than 2 ~ 3 times $\rightarrow$ 18 ~ 27 $\mu$F $\rightarrow$ standard nominal capacitance 22 ~ 33 $\mu$F

Notes:

2. In case of trapezoidal control for BLDC motor or 2-phase modulation, long ON time periods of the high-side IGBT may exist. Attention should be paid to the bootstrap supply voltage drop.

3. The above result is only a calculation example. It is recommended that actual PWM patterns and lifetime of components should be considered in the design.
3.2. Selection of Bootstrap Resistor (R_{BS})

A resistor must be added in series with the bootstrap diode to slow down the dV_{BS}/dt and determine the time to charge the bootstrap capacitor. If the minimum ON pulse width of low-side IGBT or the minimum OFF pulse width of high-side IGBT is t_o; the bootstrap capacitor must be charged to increase the voltage by ΔV during this period. Therefore, the value of bootstrap resistance can be calculated by Equation (2):

$$R_{BS} = \frac{(V_{CC} - V_{BS}) \times t_o}{C_{BS} \times \Delta V_{BS}}$$

where:
- V_{CC} = Supply voltage;
- V_{BS} = Minimum bootstrap voltage;
- t_o = Minimum ON pulse width;
- C_{BS} = Bootstrap capacitor value; and
- ΔV_{BS} = Ripple voltage of V_{BS}.

✓ Calculation Examples of R_{BS}:

V_{CC} = 15 V, V_{BS} = 13 V (minimum voltage)

If the rising dV_{BS}/dt is slowed significantly, it could cause missing pulses during the startup phase due to insufficient V_{BS} voltage.

3.3. Selection of Bootstrap Diode

When high side IGBT or diode conducts, the bootstrap diode (D_{BS}) supports the entire bus voltage. A withstand voltage higher than 1200 V is recommended. It is important that this diode should be a fast recovery (recovery time < 100 ns) device to minimize the amount of charge that is fed back from the bootstrap capacitor into the V_{CC} supply. Similarly, the high voltage reverse leakage current is important if the capacitor has to store a charge for long periods of time. Recommended diodes are below.

- STM: STTH112(DO-41), STTH112U(SMB)
- Vishay: EGF1T(DO-214BA), SF1200(SOD-57)
3.4. Selection of Shunt Resistor (One Shunt)

The value of shunt resistor is calculated by the following equations.

Maximum Short-Circuit (SC) current trip level (depends on user selection):

$$I_{SC(max)} = 1.5 \times I_{C(max)}$$

SC Trip Reference Voltage (depends on datasheet):

$$V_{SC} = \text{min. 0.43 V, typ. 0.5 V, max. 0.57 V}$$

Shunt Resistance:

$$I_{SC(max)} = \frac{V_{SC(max)}}{R_{SHUNT(min)}} \Rightarrow R_{SHUNT(min)} = \frac{V_{SC(max)}}{I_{SC(max)}}$$

If the Deviation of the Shunt Resistor is Limited below ± 5%:

$$R_{SHUNT(typ)} = \frac{R_{SHUNT(min)}}{0.95}, R_{SHUNT(max)} = R_{SHUNT(typ)} \times 1.05$$

Actual SC Trip Current Level becomes:

$$I_{SC(typ)} = \frac{V_{SC(typ)}}{R_{SHUNT(typ)}}, I_{SC(min)} = \frac{V_{SC(min)}}{R_{SHUNT(max)}}$$

Inverter Output Power:

$$P_{OUT} = \sqrt{3} \times V_{O,LL} \times I_{RMS} \times PF$$

where:

MI = Modulation Index;

$$V_{O,LL} = \text{Line to Line Voltage} = \frac{\sqrt{3}}{\sqrt{2}} \times MI \times \frac{V_{DC\_Link}}{2}$$

$$V_{DC\_Link} = \text{DC link voltage;}$$

$$I_{RMS} = \text{Maximum load current of inverter;}$$

and

$$PF = \text{Power Factor}$$

Average DC Current:

$$I_{DC\_AVG} = \frac{V_{DC\_Link}}{(P_{out} \times Eff)}$$

where:

$$Eff = \text{Inverter efficiency}$$

The power rating of shunt resistor is calculated by the following equation:

$$P_{SHUNT} = (I_{DC\_AVG}^2 \times R_{SHUNT} \times \text{Margin}) / \text{Derating Ratio}$$

where:

$$R_{SHUNT} = \text{Shunt resistor typical value at } T_C = 25^\circ C$$

$$\text{Derating Ratio} = \text{Derating ratio of shunt resistor at } T_{SHUNT} = 100^\circ C$$

(From datasheet of shunt resistor); and

$$\text{Margin} = \text{Safety margin (determined by user)}$$
✓ Shunt Resistor Calculation Examples

Calculation Conditions:

- DUT: FSBB10CH120D
- Tolerance of shunt resistor: ±5%
- SC Trip Reference Voltage:
  - $V_{SC(min)} = 0.43$ V, $V_{SC(typ)} = 0.50$ V, $V_{SC(max)} = 0.57$ V
- Maximum Load Current of Inverter ($I_{RMS}$): 5 A
- Maximum Peak Load Current of Inverter ($I_{C(max)}$): 10 A
- Modulation Index (MI): 0.9
- DC Link Voltage ($V_{DC,Link}$): 600 V
- Power Factor (PF): 0.8
- Inverter Efficiency (Eff): 0.95
- Shunt Resistor Value at $T_C = 25^\circ C$ ($R_{SHUNT}$): 40.0 mΩ
- Derating Ration of Shunt Resistor at $T_{SHUNT} = 100^\circ C$: 70%
- Safety Margin: 20%

Calculation Results:

- $I_{SC(max)}$: $1.5 \times I_{C(max)} = 1.5 \times 10$ A = 15 A
- $R_{SHUNT(min)}$: $V_{SC(max)} / I_{SC(max)} = 0.57$ V / 15 A = 38.0 mΩ
- $R_{SHUNT(typ)}$: $R_{SHUNT(min)} / 0.95 = 38.0$ mΩ / 0.95 = 40.0 mΩ
- $R_{SHUNT(max)}$: $R_{SHUNT(typ)} \times 1.05 = 40.0$ mΩ x 1.05 = 42.0 mΩ
- $I_{SC(min)}$: $V_{SC(min)} / R_{SHUNT(max)} = 0.43$ V / 42.0 mΩ = 10.24 A
- $I_{SC(typ)}$: $V_{SC(typ)} / R_{SHUNT(typ)} = 0.5$ V / 40.0 mΩ = 12.50 A
- $V_{O,LL} = \frac{\sqrt{3}}{\sqrt{2}} \times MI \times \frac{V_{DC,Link}}{2} = \frac{\sqrt{3}}{\sqrt{2}} \times 0.9 \times 300 = 330.7$ V
- $P_{OUT} = \sqrt{3} \times V_{O,LL} \times I_{RMS} \times PF = \sqrt{3} \times 330.7 \times 5 \times 0.8 = 2291$ W
- $I_{DC,AVG} = (P_{OUT}/Eff) / V_{DC,Link} = 4.01$ A
- $P_{SHUNT} = (I_{DC,AVG}^2 \times R_{SHUNT} \times Margin) / Derating~Ratio = (4.01^2 \times 0.04 \times 1.2) / 0.7 = 2.0$ W

When over-current events are detected, 1200 V Motion SPM 3 series shuts down all low-side IGBTs and sends out the fault-out (FO) signal. Fault-out pulse width can be adjusted by the capacitor CFOD connected to the CFOD terminal. This fault duration can be calculated by the equation:

$$t_{FOD} [s] = 0.8 \times 10^6 \times C_{FOD}[F]$$

To prevent malfunction, it is recommended that an RC filter be inserted at the $C_{SC}$ pin. To shut down IGBTs within 2 µs when over-current situation occurs, a time constant of 1.5 ~ 2 µs is recommended.
3.5. Print Circuit Board (PCB) Layout Guidance

- Wiring between Nu, Nv, Nw and shunt resistor should be as short as possible.
- Place snubber capacitor between P and N and closely to terminal.
- The main electrolytic capacitor should be placed to snubber capacitor as close as possible.
- It is recommended to connect Signal GND and Power GND at only a point. (Not copper pattern and don't make a loop in GND pattern.) And this wiring should be as short as possible.
- The capacitor between VCC and COM should be placed to SPM as close as possible.
- The VIN RC filter should be placed to SPM as close as possible.
- CSC wiring should be as short as possible.
- Capacitor and Zener diode should be locate closely to terminal.
- The isolation distance between high voltage block and low voltage block should be kept.

Figure 3. PCB Layout Guidance
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